# A study on the measurement for forest ecological benefit[1]

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**Abstract** The indexes of dependent variables of the measurement on the forest ecological benefits were defined according to the analysis of the multiple ecological benefits of forest. This indexes system includes water-reserving, soil and water conservation, wind and sand suppression, microclimate improvement, carbon dioxide assimilation, atmosphere purification, flood and drought mitigation, tourism resource and wild creature protection benefits. The main factors from the numerous factors that affect dependent variables were chosen as independent variables. At last, a multivariate linear model was established for measurement of forest ecological benefit. With this multivariate linear model the forest ecological benefit of China was calculated. The forest ecological benefit of China is 723816 million yuan per year, which equals to 23.07% of the gross domestic product of China.
**Key words:** Forest ecological benefit, Measurement index system; Multivariate linear model

## Introduction

Forestry is important part of national economy, not only an industry but also a public welfare. Forest resource has ecological, economical and social benefits. At present, the study about forest ecological benefits is mainly on measurement of physical quantity, and less on measurement of economical quantity (Bateman 1991; Dwyer *et al.* 1992.) (how to transform physical quantity to economical quantity). There exist many problems on research of measurement of forest ecological benefits. For example, measurement theory is unclear, measurement units not unify, and dependent variables and independent variables is not clear (Lang *et al.* 2000) In this paper, we measured the forest ecological benefit of China by established the multivariate linear model.

## Materials and methods

### Data collection

For the wide scope of our study, the data we need should cover more area. Leaded by this thought, we collected lots of data from different time, different areas and different stands of China in two years. These data are mainly from papers of periodicals (An 1988; Chen *et al.* 1986; Deng 1984; Hou *et al.* 1995, Lu *et al.* 1985; Wu *et al.* 1992; Zhou *et al.* 1994). The scholars take different measurement indexes and units with their different starting points. Therefore, according to the index system defined next, we build our database by regional independent variables, stand independent variables and dependent variables with unified units.

### Variables

Three types of variables were used in this paper.

Dependent variables:

$Y_1$=water-reserving benefit of forest, million yuan/a

$Y_2$=soil and water conservation benefit of forest, million yuan/a

$Y_3$=wind and sand suppression benefit of forest, million yuan/a

$Y_4$=microclimate improvement benefit of forest, million yuan/a

$Y_5$=carbon dioxide assimilation benefit of forest, million yuan/a

$Y_6$=atmosphere purification benefit of forest, million yuan/a

$Y_7$=flood and drought mitigation benefit of forest, million yuan/a

$Y_8$=tourism resource benefit of forest, million yuan/a

[1] This study is one part of national project of forestry ecological engineering and measuring evaluation of ecological benefits for forest ecosystem.

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$Y_9$=wild creature protection benefit of forest, million yuan/a

Regional independent variables:

$X_1$=longitude (°)

$X_2$=latitude (°)

$X_3$=altitude, m

$X_4$=annual precipitation, mm

$X_5$=mean annual wind speed, m/s

$X_6$=annual accumulated temperature ≥10℃, ℃

Stand independent variables:

$X_7$=forest accumulation, ten thousand $m^3$

$X_8$=forest coverage rate, %

The basic statistic values of each variable were listed in Table 1.

**Table 1. The basic statistic values of each variables**

| Variables | Mean | Minimum | Maximum |
|---|---|---|---|
| Longitude (°) | 112.07 | 88.08 | 126.10 |
| Latitude (°) | 33.43 | 20.03 | 47.60 |
| Altitude, m | 602.25 | 4.50 | 3702.60 |
| Annual precipitation, mm | 979.65 | 275.90 | 2429.10 |
| Mean annual wind speed, m/s | 2.51 | 1.00 | 4.30 |
| Annual accumulated temperature≥10℃, ℃ | 4522.08 | 2037.30 | 7880.00 |
| Forest volume, $m^3$ | 326973700 | 106200 | 2053798000 |
| Forest coverage rate, % | 1947 | 35 | 5060 |
| Water-reserving benefit, million yuan/a | 4742 | 17 | 14282 |
| Soil and water conservation benefit, million yuan/a | 5205 | 21 | 15730 |
| Wind and sand suppression benefit, million yuan/a | 228 | 35 | 5060 |
| Microclimate improvement benefit, million yuan/a | 3235 | 225 | 8264 |
| Carbon dioxide assimilation benefit, million yuan/a | 3641 | 34 | 12393 |
| Atmosphere purification benefit, million yuan/a | 3482 | 33 | 11870 |
| Flood and drought mitigation benefit, million yuan/a | 1910 | 11 | 7090 |
| Tourism resource benefit, million yuan/a | 88 | 0.06 | 470 |
| Wild creature protection benefit, million yuan/a | 469 | 0.06 | 2340 |

## Models

By research and analysis, we build the multivariate linear model of forest ecological benefit as follows.

$Y=BX+E$

Where:

$Y=[Y_1, Y_2, Y_3, Y_4, Y_5, Y_6, Y_7, Y_8, Y_9]^T$

$X=[X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8]^T$

$B$, $E$ are coefficient matrix and constant matrix.

Estimate and test the parameters in this model, the result is listed as follows:

$$B=\begin{pmatrix} -0.4388 & -3.2096 & -0.0202 & 0.0120 & 0.0000 & 0.0000 & 0.0005 & 0.0000 \\ 0.0629 & -1.4154 & -0.0203 & -0.0004 & -9.8838 & 0.0000 & 0.0008 & 0.0000 \\ 0.0629 & 0.1487 & -0.00002 & 0.0000 & -1.1316 & 0.0000 & 0.00003 & 0.0608 \\ 0.2123 & 1.0068 & -0.0043 & 0.0275 & 0.0000 & 0.0016 & 0.0000 & 0.0016 \\ 0.5682 & -0.5609 & -0.0084 & 0.0000 & 0.0000 & 0.0000 & 0.0006 & 0.0000 \\ 0.5440 & -0.5265 & -0.0081 & 0.0000 & 0.0000 & 0.0000 & 0.0006 & 0.0000 \\ 0.1289 & -0.1894 & -0.0067 & -0.0014 & 0.0000 & 0.0000 & 0.0003 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.000008 & 0.0298 \\ 0.0319 & 0.1938 & -0.0008 & 0.0000 & 0.0000 & 0.0000 & 0.0001 & 0.1267 \end{pmatrix}$$

$$E=\begin{pmatrix} 187.3964 \\ 116.5590 \\ -9.0108 \\ -58.1190 \\ -22.4565 \\ -21.8288 \\ 5.0718 \\ 0.0265 \\ -10.2038 \end{pmatrix}$$

The correlation coefficient and significance tests are listed in Table 2.

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From these statistical results, we can find that the regression relationship of these variables is very significantly.

**Table 2. Correlation coefficient and significance tests**

| Dependent variables | Correlation coefficient | $R_{0.05}$ | $R_{0.01}$ | significance |
|---|---|---|---|---|
| $Y_1$ | 0.736516609 | 0.5383 | 0.6105 | ** |
| $Y_2$ | 0.856155423 | 0.5644 | 0.63324 | ** |
| $Y_3$ | 0.815430587 | 0.5711 | 0.6403 | ** |
| $Y_4$ | 0.603613173 | 0.5711 | 0.6403 | * |
| $Y_5$ | 0.818903159 | 0.5138 | 0.5906 | ** |
| $Y_6$ | 0.8198676 | 0.5138 | 0.5906 | ** |
| $Y_7$ | 0.8363208 | 0.5449 | 0.6175 | ** |
| $Y_8$ | 0.517803377 | 0.4255 | 0.5142 | ** |
| $Y_9$ | 0.844666427 | 0.5449 | 0.6175 | ** |

## Measurement

With this model and the values of each independent variables of each province of China, we can calculate the forest ecological benefits of each province. The results were listed in Table 3.

**Table 3. Forest ecological benefits value**

| Province | $Y_1$ | $Y_2$ | $Y_3$ | $Y_4$ | $Y_5$ | $Y_6$ | $Y_7$ | $Y_8$ | $Y_9$ |
|---|---|---|---|---|---|---|---|---|---|
| Beijing | 15.64 | 27.71 | 2.33 | 30.48 | 21.39 | 20.57 | 11.64 | 0.48 | 3.13 |
| Tianjin | 17.52 | 23.80 | 1.25 | 29.70 | 22.25 | 21.38 | 11.91 | 0.25 | 2.05 |
| Hebei | 24.27 | 41.27 | 2.72 | 26.30 | 24.04 | 23.07 | 13.35 | 0.47 | 2.84 |
| Shanxi | 24.03 | 33.13 | 1.44 | 23.40 | 22.09 | 21.21 | 12.58 | 0.30 | 1.99 |
| Inner mongolia | 46.36 | 99.44 | 5.18 | 16.90 | 66.01 | 63.24 | 38.58 | 1.11 | 9.99 |
| Liaoning | 8.41 | 22.92 | 3.28 | 33.98 | 30.00 | 28.81 | 15.11 | 0.94 | 6.25 |
| Jilin | 31.94 | 62.28 | 4.62 | 33.05 | 66.06 | 63.34 | 36.13 | 1.63 | 12.74 |
| Heilongjiang | 56.30 | 112.6 | 6.86 | 33.06 | 100.5 | 96.28 | 56.47 | 2.16 | 18.35 |
| Shanghai | 40.36 | 33.91 | 0.01 | 21.57 | 29.02 | 27.79 | 14.05 | 0.10 | 0.02 |
| Jiangshu | 45.42 | 37.20 | 0.43 | 36.05 | 27.51 | 26.37 | 13.03 | 0.15 | 0.37 |
| Zhejiang | 56.95 | 52.67 | 3.30 | 32.50 | 34.72 | 33.46 | 16.32 | 1.38 | 5.70 |
| Anhui | 54.18 | 41.89 | 1.38 | 50.29 | 29.59 | 28.50 | 13.60 | 0.56 | 2.45 |
| Fujian | 85.59 | 70.89 | 2.92 | 33.11 | 49.69 | 48.32 | 23.29 | 1.79 | 7.88 |
| Jiangxi | 72.93 | 47.37 | 1.62 | 49.15 | 37.69 | 36.51 | 17.05 | 1.37 | 5.78 |
| Shandong | 38.04 | 26.45 | 1.01 | 55.16 | 26.44 | 25.41 | 11.86 | 0.36 | 2.14 |
| Henan | 31.00 | 26.96 | 0.56 | 27.01 | 22.91 | 22.08 | 11.49 | 0.38 | 1.71 |
| Hubei | 52.05 | 46.39 | 1.32 | 26.10 | 31.50 | 30.45 | 15.75 | 0.76 | 3.17 |
| Hunan | 53.36 | 45.78 | 2.19 | 38.23 | 30.55 | 29.64 | 15.22 | 1.13 | 5.16 |
| Guangdong | 88.54 | 69.27 | 2.02 | 40.72 | 38.65 | 37.33 | 18.13 | 1.25 | 4.17 |
| Guangxi | 86.28 | 70.03 | 2.44 | 51.06 | 37.84 | 36.71 | 17.64 | 1.25 | 4.74 |
| Hainan | 95.64 | 60.26 | 0.15 | 40.22 | 32.31 | 30.96 | 14.97 | 1.00 | 1.72 |
| Sichuan | 119.6 | 149.2 | 6.00 | 49.62 | 93.54 | 92.86 | 45.97 | 1.68 | 14.29 |
| Guizhou | 43.69 | 28.43 | 0.29 | 20.85 | 16.81 | 16.20 | 5.47 | 0.54 | 2.47 |
| Yunnan | 93.36 | 102.5 | 3.45 | 20.66 | 72.28 | 71.85 | 32.39 | 1.64 | 10.57 |
| Xizhang | 96.44 | 137.6 | 5.20 | 14.45 | 105.16 | 105.71 | 46.48 | 1.84 | 16.81 |
| Shanxi | 43.50 | 56.40 | 2.89 | 24.12 | 33.00 | 31.59 | 18.48 | 0.97 | 5.01 |
| Gansu | 12.83 | 28.02 | 2.63 | 11.61 | 8.43 | 8.08 | 5.51 | 0.29 | 1.42 |
| Qinghai | 2.16 | 3.41 | 1.11 | 12.63 | 2.92 | 1.69 | 1.09 | 0.06 | 0.27 |
| Ningxia | 0.63 | 7.83 | 1.52 | 12.42 | 3.51 | 3.38 | 1.42 | 0.08 | 0.09 |
| Xinjiang | 3.85 | 19.28 | 1.23 | 15.21 | 6.05 | 5.92 | 8.90 | 0.02 | 3.01 |
| Taiwan | 75.20 | 37.50 | 2.52 | 66.13 | 36.83 | 35.70 | 11.84 | 1.85 | 6.59 |

Because of the error caused by the model construction, when we calculate the ecological benefit of the areas with high altitude and low forest coverage rate, the value may be negative (here is Qinghai Province). Because the forest ecological benefit cannot be negative, we use observed value to take place of predicted value.

## Conclusion

According to the study of forest ecological benefits we can find that:

(1) By study and analysis we can construct the multivariate linear model of forest ecological benefit measurement as follows:

$$Y=BX+E$$

With this model, we can calculate the forest

ecological benefit of China is 72 3816 million yuan/a. It is equal to 23.07 percentage of the gross domestic product of China.

In the forest ecological benefit of China we can find that: The water-reserving benefit is 151 607 (20.95%) million yuan/a. The soil and water conservation benefit is 162 239 (22.42%) million yuan/a. The wind and sand suppression benefit is 7 387 (1.02%) million yuan/a. The microclimate improvement benefit is 97 574 (13.48%) million yuan/a. The carbon dioxide assimilation benefit is 115 929 (16.02%) million yuan/a. The atmosphere purification benefit is 112 441 (15.53%) million yuan/a. The flood and drought mitigation benefit is 57 572 (7.95%) million yuan/a. The tourism resource benefit is 2 779 (0.38%) million yuan/a. The wild creature protection benefit is 16 288 (2.25%) million yuan/a.

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